MULTI-SENSOR ORDNANCE DETECTION AND MAPPING SYSTEM

Michael Kerr
Air Force Research Laboratory AFRL/MLQC
104 Research Road Bldg 9738
Tyndall AFB, Fl 32403-5353
850 283 3725 FAX 850 283 9710
mkerr@robosun.tyndall.af.mil

UXO Detection

Abstract

The Air Force Research Laboratory (AFRL), Tyndall AFB, has developed a semi-autonomous unexploded ordnance (UXO) detection, characterization, and mapping system. The system is comprised of two major functional components, an unmanned autonomous tow vehicle (ATV) and a multi-sensor data acquisition system. By combining an ATV, its highly accurate position and mapping systems, and a multi-sensor platform, operators' plan, execute, and analyze collected data while monitoring vehicle and data acquisition system functions at a safe distance from the survey site. The integration of Global Positioning System (GPS) data and an Inertial Navigation System (INS) provides positional accuracy approaching 2 cm with update rates of approximately 10 Hz. Accurate time and position information is tagged to either singular or multiple sensor system collected data. A path-planning subsystem provides complete survey site coverage, survey site repeatability, and accurate site mapping. Finally, the multi-sensor data acquisition system with its simple control and interface specifications provides a highly dynamic platform essential for the integration of varying sensor suite configurations.

The current multi-sensor suite, an array of four cesium vapor magnetometers, three EM61 inductance coils, and an impulse ground penetrating radar (GPR) system defines a highly capable UXO detection system. Each integrated sensor suite's operating characteristics have been optimized, singularly, for target detection with 5 to 30 cm error rates and aggregately for preliminary target discrimination. To date, data collection has been conducted at Tyndall AFB, Jefferson Proving Grounds (JPG), Richard Gebaur AFB, Eglin AFB, and the YUMA Army Research Laboratory (ARL) Boom SAR test site.

The multi-sensor ordnance detection and mapping system has been demonstrated as a useful UXO site detection and mapping tool. However, it is not limited to only UXO detection, the ability to integrate varied sensor suite configurations as well as execute and manage autonomous site survey operations have demonstrate usefulness in site characterization, sensor performance analysis and post clean-up site verification operations.

System Description

The characterization system is composed of the Autonomous Tow Vehicle (ATV), a Multiple Sensor Platform (MSP), and the Mobile Command Station (MCS). The ATV performs autonomous surveys of designated areas and provides the data collection system with time and position information. The MSP acts as a non-magnetic instrument carrier for testing sensor performance, and a data collection platform. The MCS acts as the base station for control of the vehicle by the operator. It contains the operator interface, GPS base station, and the data analysis and display computers.

The characterization task is performed by autonomously sweeping a designated area with the Autonomous Tow Vehicle (ATV). The ATV tows the multiple sensor platform (MSP) containing a magnetometer array, an array of inductance coils, and a ground penetrating radar (GPR). The ATV provides the time and position stamp for sensor data. Analysts then review the post survey sensor data to determine ordnance position. The ATV makes use of several advanced technologies. A hybrid navigation and guidance system using an external Kalman filter delivers vehicle position based on information from a Differential Global Positioning System (DGPS) and an Inertial Navigation System (INS). Sophisticated path planning algorithms, and intelligent software architecture provide a measure of autonomy. A data collection system controls the functions of the various sensors.

Autonomous Tow Vehicle

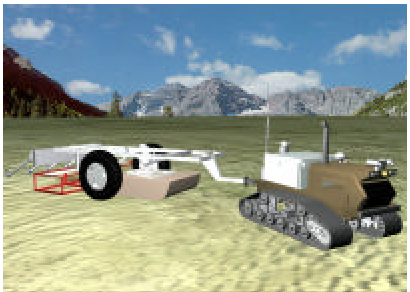

Figure 1:
Active Range Ordnance Mapping System
(AROMS)

The ATV consists of several integrated subsystems; the vehicle itself, the vehicle electronics subsystem, which provides for computer control of the vehicle, the navigation system, which provides time and position information, generates the path plan, and controls the vehicle during path execution, the communication system, which provides telemetry information for the GPS system, a video channel from the vehicle to the mobile command station, and a two way data link that transmits and receives status and command information from the operator, and finally, the data collection subsystem, which controls the sensors aboard the sensor platform, collects the sensor data during survey operations, and stores the data for later analysis. AFRL has developed two ATV systems, the Active Range Ordnance Mapping system (AROMS), Figure 1, and its predecessor, the Subsurface Ordnance Characterization System (SOCS), Figure 2.

Figure 2:
Subsurface Ordnance Characterization System
(SOCS)

Multiple Sensor Platform

Figure 3:
Multiple Sensor Platform
(MSP)

The Multiple Sensor Platform, as its name implies, provides a mounting structure for an array of Cesium Vapor Magnetometers, an array of EM61 inductance coils, and a hanger for a Ground Penetrating Radar system. The GPR is suspended below the platform frame via a pinned hanger. The magnetometers and inductance coils are hung from articulated beams located at the rear of the MSP. The MSP is manufactured from non-magnetic and composite materials and is designed to minimize platform to sensor interference. Encoders located at each axle measure relative traveled distance. An encoder at the GPR hanger point measures the relative GPR angular displacement from the platform frame. The MSP can be extended and/or collapsed as required per sensor sensitivity and/or operational requirements and is highly robust allowing for many variations in sensor configurations.

Mobile Command Station

The Mobile Command Station (MCS) contains the operator station, the GPS base station, and the radio base station. The MCS is a self-powered unit, providing 10kW of 110 VAC through the onboard generator. The MCS is divided into two halves. The rearward half is used to shelter and transport the ATV; it also provides storage for tools and miscellaneous equipment. The forward half houses the operator control station and contains the computers and electronics for the operator computer graphic interface, monitors for video feedback, the joystick control box for tele-operation, the radio base station, and the GPS base station. The GPS base station provides the stationary link for differential GPS processing. The radio base station provides the command and control radio link to the tow vehicle. The operator control station provides the operational, sensor control, vehicle control, and video feedback interface to the tow vehicle. Figure 4 illustrates the current MCS configuration. From the MCS, the operator is capable of invoking an autonomous survey, performing tele-operated functions, reviewing diagnostic information, and viewing video feedback.

Figure 4: Mobile Command Station

Data Collection System

The data collection system controls, monitors, and manages all sensor, data collection and data storage processes. During data collection three basic file types are written and stored, navigation, platform and sensor data. The following bullets illustrate each file type as well as output format:

- **Navigation File Example**

Keyword \ time (Julian DDD.HH.MM.SS.ssssss) \ latitude \ longitude \ RMS \ elevation (meters) \
NavRec \ 062.20.37.01.400000 \ 032.9111194 \ -114.4060232 \ 00.2341 \ 107.791588 \\
NavRec \ 062.20.37.01.590000 \ 032.9111193 \ -114.4060234 \ 00.2352 \ 107.791740 \\

- **Platform File Example**

Keyword \ time \ vehicle pitch \ vehicle roll \ vehicle yaw \ hitch pitch \ hitch roll \ hitch yaw \ GPR pitch
PlatformRec \ 062.20.37.00.836390 \ 082.62 \ +000.59 \ -005.46 \ +359.69 \ +001.41 \ +011.43 \ +359.29\
PlatformRec \ 062.20.37.00.886474 \ 082.62 \ +000.59 \ -005.46 \ +359.69 \ +001.41 \ +011.43 \ +359.29\

- **Magnetometer File Example**

Keyword \ time \ serial number \ sensor A sensor B sensor C sensor D
SensorRec \ 062.20.37.01.136429 \ mag1234 \A4842459958B4842911095C4843890089D4843414891\\
SensorRec \ 062.20.37.01.186417 \ mag1234 \A4842459541B4842910070C4843889499D4843414468\\

- **Inductance Coil File Example**

Keyword \ time \ serial number \ Set Left Set Middle Set Right
e61Rec\062.22.14.23.654706\em6123\TT+0614+0067127 TT+0289+0008127 TT+0361+0011127\
e61Rec\062.22.14.23.754768\em6123\TT+0614+0068127 TT+0288+0008127 TT+0359+0010127\

- **GPR File Example**

Keyword \ time \ serial number \ binary data
gprRec\064.21.55.10.444692\gpr1234\"524 bytes binary data"

Navigation System

The navigation system provides the means for the autonomous survey of a given area. The operator must provide information regarding the boundary of the area of interest and any obstacles contained within that area. Given this information the system will perform the following: (1) autonomously navigate the vehicle from its current position to the edge of the field to be surveyed; (2) plan an efficient path which targets 100% coverage of the field with a user specified overlap for each swath; (3) autonomously execute the planned path, collecting sensor data while avoiding collisions with expected or unexpected obstacles. These tasks are performed by three subsystems: the Path Planner, the Positioning System, and the Path Executioner.

Path Planner

The area to be surveyed is assumed to contain regions where the vehicle is prohibited from operating. Buildings, trees, telephone poles, lakes, and other obstacles are represented as polygonal shapes and stored in an area map. A path planner is used to generate an efficient path from the starting position to a position at the beginning of the path for the area to be swept, from an area that has just been swept to another survey area, or back to the starting point[1].

Survey Path Planner

A field is modeled by an N-sided polygon. Two adjacent vertices, A and B, are chosen and used to generate parallel rows across the field. The rows are separated by a user defined swath width, L, which represents the width of the detection system, plus a desired overlap. Point A is the start position for field sweeping. Point B is required to be the point next to A, such that the motion from A to B is clockwise motion around the boundary. The line segment AB corresponds to row #1.

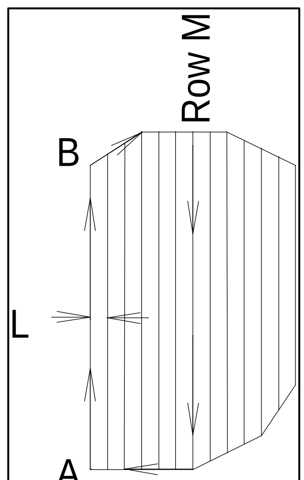

Figure 5: Half Field Method

The endpoints of the rows are used to define the path to be followed, where K is the number of rows to be swept for the field. Each row is checked for intersection with the obstacles loaded into the database. Wherever an intersection is encountered, an alternate route around each side of the obstacle is examined. The shortest detour is incorporated into the total field sweep path.

The current sweep pattern used for the survey vehicle is the "Half Field Method," see Figure 5. Row #1 is swept followed by the middle row M, where M=K/2. Next, row #2 is swept followed by the middle row (M+1). This pattern is continued until the entire field has been swept. This method does not require a row be swept more than once except when K is odd. In such cases, row M is swept twice.

Positioning System

To successfully navigate along a pre-planned path, the ATV must have some means of accurately and consistently determining its position and orientation. This problem has been addressed by the application of an inertial navigation system, INS, integrated with a differential global positioning system, GPS.

The ATV uses the Modular Azimuth Position System, MAPS for inertial navigation. The MAPS is a completely self contained, strapped down, laser gyro system. Given an initial position, the MAPS makes use of its three ring laser gyros and three accelerometers to determine relative position, angular orientation, and velocities. Position and orientation data from the MAPS are made available at a rate of 12.0 Hz. The MAPS makes use of velocity updates to dampen velocity errors that cause drift in the position accuracy over time.

To achieve high resolution position data, a method known as differential GPS is applied: A GPS receiver is placed at a known pre-surveyed location, the base station. A second remote GPS receiver is placed on the moving vehicle. Using apriori knowledge of its position, the base station receiver can determine the systematic or bias errors from the incoming signal. The corrections are then transmitted to the remote vehicle. Position data have been found to be accurate in the range of 2-10 centimeters 85% of the time using this method.

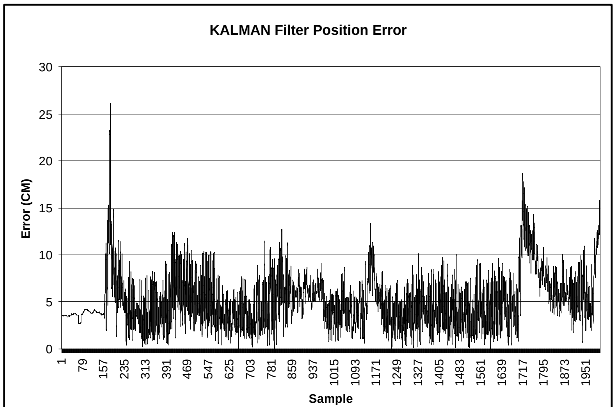

Figure 6: ATV/MSP Position Error

The integration of the GPS with the MAPS has greatly increased the overall system performance. The two systems complement each other well in that the MAPS provides continuous data at high rates while the GPS system is not subject to drift. The external software Kalman filter uses models of the navigation instruments used, and an error history of these same instruments to predict current vehicle position. This system provides a robust means for acquiring position during intermittent dropouts or spurious instrument errors.

Sensor Descriptions

In its current configuration, the ATV/MSP system contains three sensor systems: an array of four total flux magnetometers, an array of three electromagnetic inductance coils, and a ground penetrating radar system. The following sections briefly describe their capabilities.

Magnetometers

The ATV/MSP Magnetometer array is composed of four EG&G Cesium Vapor Magnetometers spaced 50 cm on center. These magnetometers exhibit a noise floor of approximately 1 gamma.


Figure 7: Cesium Vapor Magnetometers

Inductance Coils


Figure 8: EM61 Inductance Coils

The ATV/MSP Inductance Coil Array is composed of three Geonics EM-61 one meter coils. Each coil has a maximum output of 40,000 mV. The coils measure two channels of secondary response in mV. The coils are mounted side by side perpendicular to the long axis of the sensor trailer providing a three-meter sweep width.

Ground Penetrating Radar

In general, the ATV/MSP GPR transmits a series of 3-5 nsec 100-250 volt impulses into the ground at specific pulse repetition interval (PRI). Received signals from objects with varying electrical properties from the surrounding soil are fed through an adjustable attenuator, band pass filter, and finally to track and hold circuitry which digitizes and stores collected data. The system uses a single broad bandwidth bow tie antenna, which covers a frequency range of 20 - 250 Mhz.

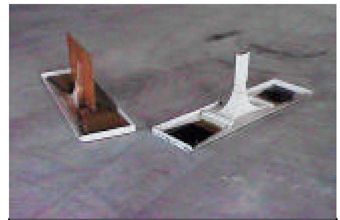

Figure 9: Bow Tie GPR

Site Descriptions

Volumes of data have been collected at several sites: Tyndall AFB, Eglin AFB, Richards-Gebaur AGB, and Yuma Proving Grounds. The data collected at Tyndall and Yuma contained inert items placed at specific locations with the express intent of demonstrating and evaluating the capability and performance of UXO detection systems. In-situ site characterizations were conducted at Richards-Gebaur and Eglin AFB. As will be explained in later sections, the collected data is both deep and rich in content and quality directly attributed to the use of hybrid positioning and site survey methodologies. The site descriptions also provide a means to assess both the characteristics of the data collected and the inherent capabilities of the ATV/MSP system. The autonomous mobility systems and the data collection systems have performed, and continue to perform, flawlessly, with minimal downtime attributed to vehicle control or data collection sub-system failures. Reports have been generated for each of these sites and are available through the AFRL/MLQC

Tyndall Air Force Base

All initial testing of the robotic platform and sensor systems was performed at Tyndall Air Force Base. The test site in the 9700 area of Tyndall AFB is composed of a loose sandy top layer approximately 20 cm deep and a packed sandy layer reaching to the water table which starts at a depth of less than 1 meter. The Tyndall test area, Figure 10, is located on a peninsula and therefore tides and rain can exaggerate variations in water table depth and thus soil conditions. The test site provides a homogenous background in which inert ordnance items; 60-mm mortar shells, 105-mm artillery shells, miscellaneous clutter, angle iron, barbed wire, concrete blocks, and steel plates were placed to simulate an active range, Figure 11. An excellent description of the test site is contained in [n[2], Barron Assoc. Report]. Data collected at the Tyndall test site includes, magnetometer, Inductance, and GPR. Figure 12 illustrates typical data output plots.

Figure 10: AFRL 9700 Compound Area

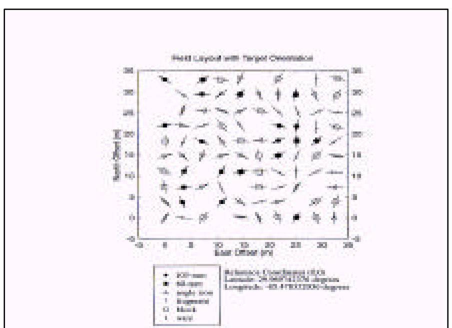

Figure 11: TAFB Test Site Ordnance Map

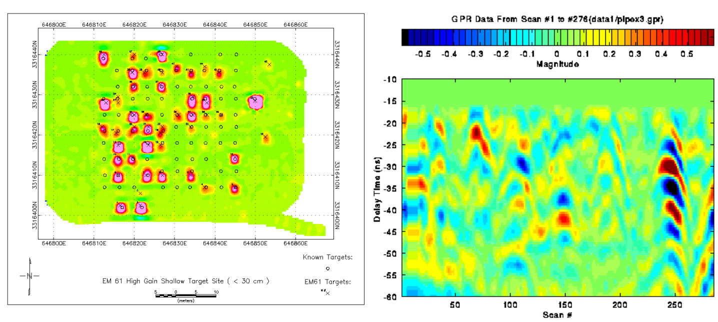

Figure 12: Em61 & GPR Data Plots

Eglin Air Force Base C-52

The Eglin EOD test area, in which site characterization was requested, was used for NAVEOD live ordnance testing and training. The area surveyed was construction site “D”, Figure 13, future home for the NAVEOD Air/Ground ordnance facility. Previously utilized as a live bombing range, interviews with EOD personal did not rule out the possibility that live munitions may exist at the site. The site was littered with debris, most of which were identifiable ordnance items or portions thereof. As an active construction site at the time of the survey, the site was cluttered with steel pilings, steel signs, rebar, wire rolls, lift stations, cement blocks, pea rock piles, miscellaneous construction trash, and a semi trailer. The center of the survey area contains the slab for the Air/Ground Ordnance facility. The slab was populated with rebar, wire mesh, and steel support beams. A black top access road borders the front perimeter of the survey area with the remainder lined with scrub oaks and pine trees. The tree line was cluttered with debris such as pieces of chain, miscellaneous metal fragments, and other identifiable ordnance items. Soil type is predominately sand and sandy loom, moisturize content was considered dry to depths of approximately one meter.

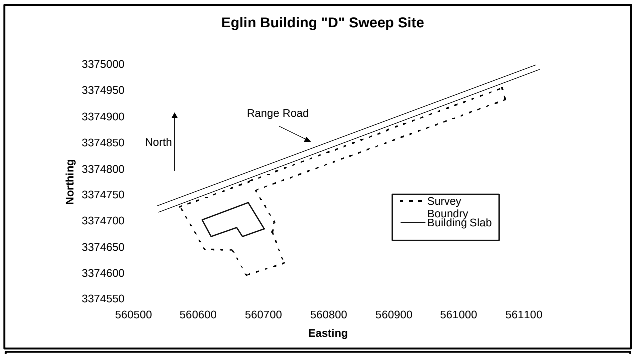

Figure 13: Eglin Survey Site and Building Boundary

Eglin Air Force Base C-62

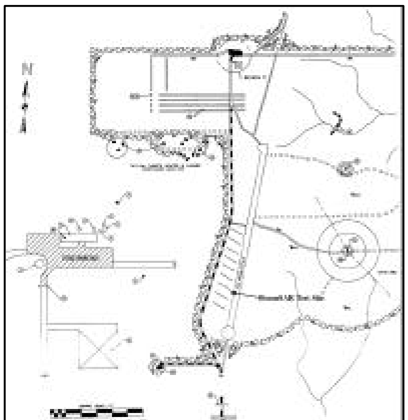

Figure 14: Eglin C-62

Eglin C-62 site characterization was conducted in support of the Army Research Lab’s development of a Boom SAR UXO target test site. The site characterization objective was to autonomously survey the ARL planned target range while collecting sensor data from a single EM61 inductance coil. Collected sensor data was then analyzed with generated detected target survey plots and geo-correlated detected target listing information delivered to ARL personnel. The Eglin C-62 test range is an active practice bombing target range, which is literally littered with debris and identifiable ordnance items. Figure 14 illustrates the general location of the Boom SAR test target area within Eglin C-62 bombing range. The site is generally flat, and had been freshly mowed with obstructions consisting of indigenous tortoise nests and observation towers placed at approximately 100-meter intervals, Figure 15. Soil type is predominately sand and sandy loom, moisturize content was considered dry to depths of approximately one meter.

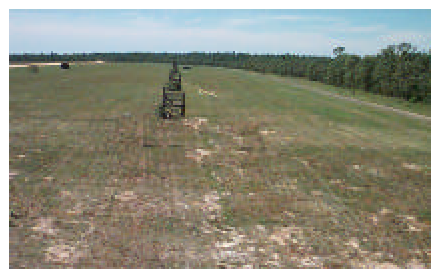

Figure 15: Site Overview

Richards-Gebaur

In support of the environmental cleanup process for Richards-Gebaur Air Guard Base, the AFRL/MLQC Robotics Group performed a site characterization of a portion of the Belton Training Complex (BTC). This survey was conducted in response to a request from the Air Force Reserve Explosive Ordnance Disposal (EOD) Team. Evaluation of potential health risks and recommendations for the subsequent cleanup efforts are the responsibility of the U.S. Air Force Base Conversion Agency, Installation Restoration Program. This ordnance contamination survey was performed from 15 - 26 July 1996 on approximately 24 acres in the BTC. Historic records indicating a high probability of residue from munitions, open burning, and ordnance waste at the BTC made it an ideal candidate for the demonstration.

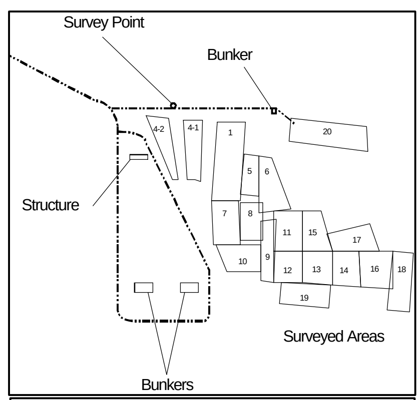

Figure 16: Richards-Gebaur Survey Site

The BTC had not been used for testing and training for a number of years. The area has become overgrown with vegetation and hosts a tall grass prairie community with moist savanna wooded areas. Wetland vegetation, including willow, cattails and sedges is present along drainages where water pools and maintenance activities have been precluded over time. The BTC landscape included a variety of gullies, trees and hills. Slopes on the hills did not exceed 10 degrees. Holes and gullies however included vertical drop-offs to depths of 18 inches with fording widths of 12 to 36 inches. Stands of trees were left but the grass and thicket were cut down.

Yuma Proving Ground

The objective of site characterization at YPG, Yuma Arizona was to demonstrate and evaluate the general performance of the Subsurface Ordnance Characterization System (SOCS). GPR, Magnetometer, and EM61 inductance coil data was collected from surveys of the Yuma Phillips drop zone site and compared to previously collected ARL Boom SAR data and published in a separate report. Multi-Sensor, simultaneous, data collections were conducted, namely, GPR and magnetometer as well as cursory **data fusion** of magnetometer and inductance coil sensor data. A general list of Dem/Val objectives follows:

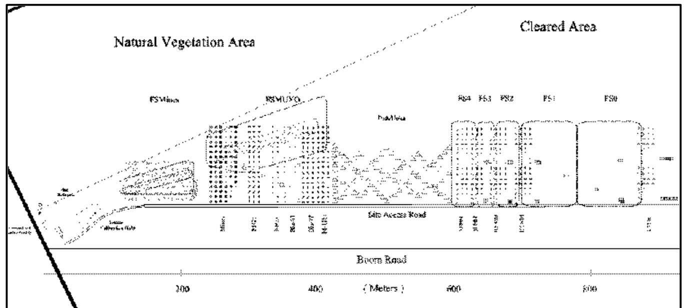

Figure 17: YPG Test Site and Ordnance Map

- Map test area boundaries, pertinent man-made and geologic landmarks and obstacles. Map survey area and individual field sweep areas.
- Assist Ohio State Universities' ElectroSceince Laboratory (OSU-ESL) in optimal GPR configuration for subsequent GPR data collection. This task includes calibration of the impulse GPR system with respect to soil conditions (dielectric constant), antenna configurations, controller gain slope profiles, and time gating.
- Collect GPR data and provide processed raw data to Battelle Laboratories for subsequent SAR processing.
- Collect magnetometer data and provide processed raw data to AETC for subsequent analysis. AFRL personal will conduct in situ magnetometer analysis.
- Collect EM61 inductance coil data and provide processed raw data for further analysis. . AFRL personal will conduct in situ inductance coil analysis.
- Observe and document overall system performance.

The Yuma test site, Figure 17, consisted of a predominately flat hard packed sandy surface littered with small stones and petrified wood fragments. The 1997/98 winter rains in the region introduced an unusual amount of desert vegetation. Although the soil surface is typically dry, several inches below the surface remained relatively moist during the test and demonstration. Soil samples were taken by Dr. Jonathan Young, of the University of Ohio to determine the soil's dielectric properties and current moisture levels.

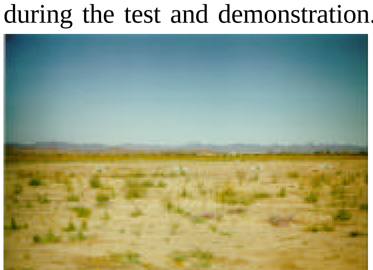

Figure 18: Yuma YPG Site

An undisturbed natural environment of various native species of cactus and brush surrounds the cleared test site, Figure 18. Within the cleared test area, the ATV/MSP was limited only by the larger ordnance exposed on the surface and by some of the larger surface rocks. Most of the exposed ordnance could pass beneath the ATV/MSP and its sensors, but contact would have displaced these items from their recorded positions and orientations. "Stay-Out" zones, or rows, were established to minimize displacement of items within the test field. Even with this restriction, the ATV/MSP vehicle was capable of surveying almost all of the target area.

Analysis

Initially the purpose of this system was to evaluate the performance of various sensors used to detect subsurface UXO. However, it soon became obvious that the same system constraints used to perform sensor comparisons were also extremely powerful aids in the data analysis process. The system characteristics of tightly coupled position and data samples, completeness of coverage for a given search area, the ability to vary and constrain the width between successive search paths, the ability to vary sample frequency with a constant and known vehicle speed, and the ability to vary the geometric configuration of each sensor make the resulting data sets a deep and rich resource for analysis.

Data Collection Method

The Data Collection system uses time as a correlating key. The data collection process begins when the ATV surveys an area containing items of interest. The sensors mounted on the MSP collect data during this traversal and system time is stamped on each data sample as it is written to a file. The data gathered during collection is composed of several files, one file contains the system position and the time it was acquired, a second file contains the hitch (between the ATV and the MSP) angles (roll, pitch, yaw) and the time it was acquired, a third file contains the sensor data and the time it was acquired. The hitch data is used to kinematically determine the position of a given sensor relative to a common time source.

Survey Data Attributes

There are several important elements in defining the quality of the data collected: 1) the completeness of the survey performed for a defined search area, or Area Coverage, 2) point distribution, how closely and regularly spaced the data samples are, and 3) the frequency of the data collected and how it relates to the sensor capabilities and the environment of the collection site.

Area Coverage

Completeness of coverage for a given search area is important for several reasons. First, the missed area represents the physical possibility of a missed ordnance item. Secondly, it represents an area of uncertainty in the data space, so that relationships between data in successive lanes are compromised. Third, for most operations, it requires a second survey to “fill in” these missed areas. This requirement dramatically decreases the efficiency of the overall operations and significantly increases the complexity of structuring the data for analysis. The following sections discuss the advantage of conducting autonomous versus manual surveys. It must be noted that the data of interest is represented by the straight line sections of each survey. The data at the ends and in the turnings lie outside the survey area and is therefore discarded.

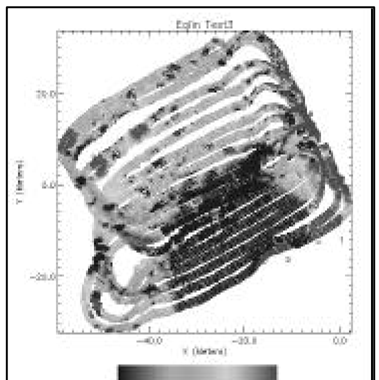

Figure 19: Eglin Manual Survey

Manual

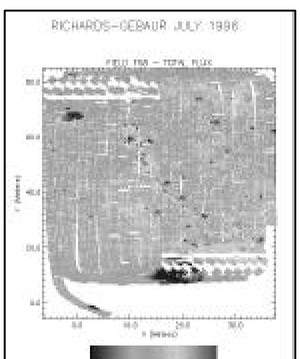

Figure 20: Richards-Gebaur ATV Survey

To show the variations inherent in performing manually operated surveys, a test was performed at Eglin AFB, Florida. The ATV and MSP were manually operated by staff EOD technicians on site. The survey area contained boundary and lane markers for the operator to follow. In addition to these, the operator also followed the tire tracks, evident in the soft sand and grass at the site, from successive lanes to align the ATV. Figure 19 illustrates the best run of the manually operated surveys conducted. As is shown, there remains significant areas that were missed during the survey. These missed areas represent a 14.6% coverage lapse that must be accounted for through re-survey, and data re-construction.

ATV Surveys

Hundreds of autonomous surveys have been conducted with the ATV and MSP. Each plot of area coverage is surprisingly consistent. Figure 20 illustrates a typical survey, and was conducted at Richards-Gebaur AGB, Missouri. It should be noted that the lane to lane coverage is quite close and, discarding the survey area ends as previously noted, is quite complete. This survey produced a 99.4% area coverage, which is quite typical for all of the autonomous surveys conducted.

Point Distribution

The distribution of points, along the line of the pathway and between successive lanes, forms the structure of the data to be analyzed. This system has been designed to build this structure according to the characteristics of each of the sensors. The sensor control system can perform both sensor data triggering and data collection for each sensor independently.

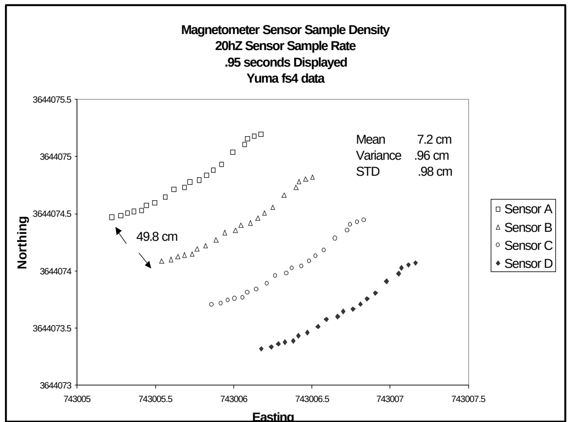

Figure 21: Magnetometer Sample Spacing

Pathway Data Spacing

This system performs pathway data spacing in two ways; vehicle speed and sensor sample speed. It is then a tradeoff with the other sensors onboard the MSP to determine the lowest common vehicle speed acceptable. The sensor sample speed is then adjusted to obtain the desired spacing. An example of this is the spacing for the magnetometers aboard the MSP. Each of the four magnetometers samples at 20 Hz, which at a vehicle speed of approximately 3 MPH, produces a spacing of about 7 cm with a variance of about 1 cm. Similar data can be shown for each of the sensors aboard the MSP. The system has the ability to collect data according to the sensor capability and the requirements of the analysis to be performed.

Lane Data Spacing

The system also provides a means for the perpendicular spacing between successive lanes. The swath width, or lane spacing, is an operator option available at the time of the survey initiation. The operator simply enters the desired lane spacing and the system calculates a path plan accordingly. The secondary means of controlling perpendicular sample spacing is simply the mounting distance between an array of sensors, as with the magnetometers and the inductance coils. The magnetometers are spaced approximately 50 cm apart (their area of influence is approximately a 50 cm radius) and the 1 m inductance coils are mounted side by side (these sensor also exhibit a 50 cm radius of capability). A typical sweep lane is shown in Figure 22. The figure shows the variation of the actual path from the calculated path. Since successive lanes exhibit similar results, the variation in spacing between lanes is approximately +/- twice the variance of a single path.

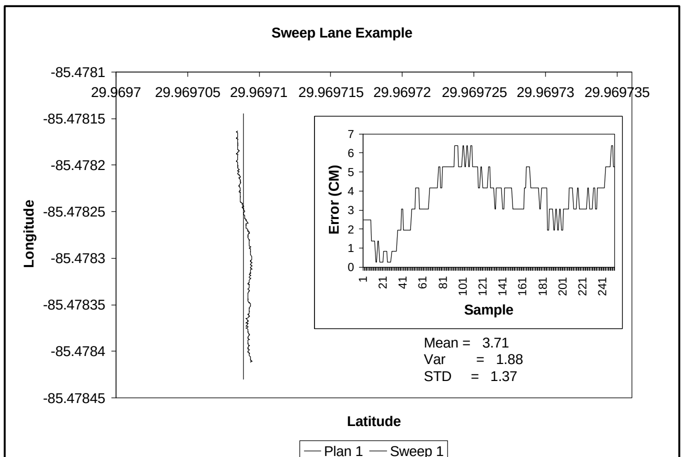

Figure 22: Variation of Sensor Path with Planned Path

Data Processing

Analysis of magnetometer, inductance coil, and GPR cursory calibration raw data is performed, in situ, at the MCS subsequent to mission completion. AFRL personal use Geosoft's Oasis Montaj UXO Target Analysis software for magnetometer and inductance coil analysis and AETC's Magproc software for supplemental magnetometer analysis. Figure 23 illustrates typical data analysis output results. Note the similarity of the two plots, this is indicative of the Multi-Sensor Ordnance Detection and Mapping system site characterization methodology. Raw position tagged sensor data from all sensors systems will map perfectly within pre-recorded survey boundaries without position interpolation or, for that matter, any type of smoothing or mathematical manipulation. Furthermore, individual survey sites can be repeated accurately within a 2 to 10 cm error in support of site verification and post remedeation certification efforts.

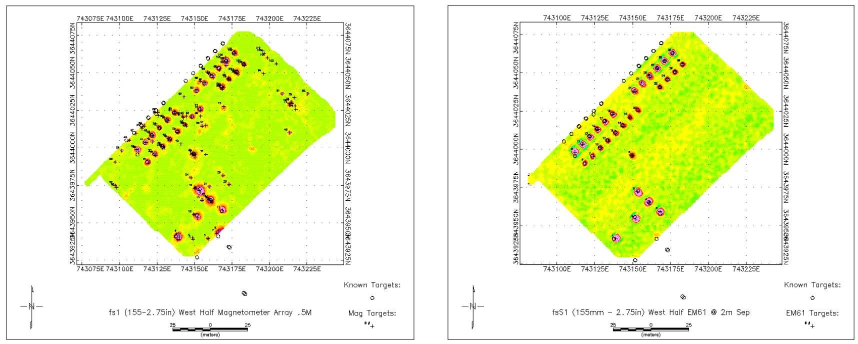

Figure 23:UXO Analysis Plots

SAR Processing.

SAR processing[3] is an extremely powerful tool used to focus the complex and large bandwidth information inherent in GPR data. In order to perform this focusing of the SAR images, the waveforms generated by the GPR must be accurately registered in the time domain, with an associated registration of position in the spatial domain. There are two ways in which the GPR data is registered to position. The first method is simply the on-board positioning system of the ATV mentioned above. A second method uses relative encoders to trigger a GPR sample every 8-cm. The encoders are mounted on the two wheels of the MSP. The encoder information from both wheels is averaged to arrive at an 8-cm distance traveled. Since the operational procedure of this system assumes that all useful data will be collected during straight-line segments within the search area, this simple approach sufficiently addresses the problem of wheel slippage during traversal. This second method provides regular sample spacing for spatial analysis methods like SAR processing, and reduces the uncertainty of position for a given sample. Due to the complex nature of SAR processing it is normally conducted off site. Figure 24 illustrates SAR processing results from Yuma Proving Ground data collections.

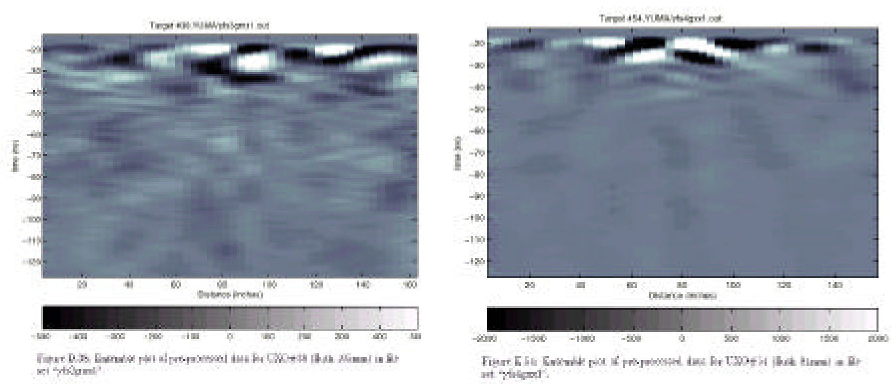

Figure 24: Yuma SAR Processed Images

Conclusion

The original intention of the ATV/MSP system was to perform evaluations of various sensor systems. It quickly became clear that its higher purpose was to provide a powerful aid to the process of analysis. The accuracy, repeatability, and completeness of coverage obtained during autonomous surveys cannot be matched through manual operations. The reliability of the system has been established through operations at widely varying environments. The data collected at these various sites demonstrate the effective application of the ATV/MPS system design. The ability to regulate the distribution of points both along the pathway and in neighboring lanes is a significant enhancement of a variety of analytic techniques dependent on spatial resolution.

[1] Rankin, A.L., “Path Planning and Path Execution Software for an Autonomous Nonholonomic Robot Vehicle, “ Master’s Thesis, University of Florida, 1993.

[2] “Target Discrimination for Subsurface Ordnance Characterization”, Dale Salmons, David Ward, USAF Contract #F08637-96-C-6013, March 1998.

[3] “SAR Processing of Ground Penetrating Radar Data for Buried UXO Detection: Results from a Surface Based System”, J Holman, K Shubert, G Ruck. Battelle Laboratory, IEEE in press.